ECOLOGICAL NOTES ON *CARLIA ROSTRALIS* IN RAINFOREST AND ASSOCIATED HABITAT IN THE SOUTHERN WET TROPICS

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A study of *Carlia rostralis* was conducted in November-December, 1988, July, 1990-92, and January-February, 1991-93, between Townsville and Cairns, Queensland, Australia. In this southern portion of its range, *C. rostralis* was locally abundant in vine thickets along creeks as well as in grassy riparian areas in open forest. It was absent from dense rainforest at higher elevations in the Seaview Ra. *C. rostralis* was restricted to the more mesic eastern localities in this southern area. Current and future conservation status of this species is excellent.

Reproductive patterns of *C. rostralis* were investigated at two locations, Waterfall Ck, Waterview Shire, and Waterview Ck, Jourama Falls NP. Adult males and females (> 45.0 mm snout vent length) were highly sexually dimorphic in both colour and maximal body size. Juveniles in their first year resembled females in colouration. Reproduction in *C. rostralis* is seasonal; egg-laying commenced in November-December and continued to February in the study. In each year, nearly all adult females in the populations observed were reproductively active. Reproductive activity coincided with the usual time of the wet season at the two localities, but seasonal rainfall did not appear to regulate the onset or the maintenance of egg-laying. ☐ *Lizard ecology, lizard reproduction, seasonal breeding, Scincidae.*

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Recent reviews of reproductive patterns in lizards that inhabit tropical environments have found that there is little relationship between seasonal environmental conditions and timing of breeding (Shine, 1985; James & Shine, 1985; Auffenberg & Auffenberg, 1989; Vitt, 1990). There appears to be a lack of general patterns of breeding in tropical lizards, despite early predictions that breeding in these areas would probably be related to seasonal rainfall. The factors that regulate the diverse patterns of breeding in tropical lizards are virtually unknown (Whittier & Crews, 1987; Whittier, 1993).

The genus *Carlia* represents an excellent model group in which patterns of seasonal breeding in tropical areas can be studied. *Carlia* comprises a total of 20+ recognised species endemic to tropical Australia, Papua New Guinea, and nearby islands (Ingram & Covacevich, 1989). No long-term studies of the status and reproductive biology of this group have been conducted previously. A few short-term studies have examined the reproductive and thermal ecology of members of this genus. Reproductive cycles of *C. rhomboidalis* and *C. schmeltzii* (originally identified as *Leiolopisma rhomboidalis* and *Leiolopisma fusca*, respectively; identification checked by examination of Wilhoft's labelled specimens in the Los Angeles County Museum, by JMW), in northeastern Queensland, and *C. bicarinata*, in eastern Papua New Guinea, indicate that these species reproduce during the wet season (Wilhoft 1963a, 1963b; Wilhoft & Reiter, 1965; Zug et al., 1982). Similarly, several species of *Carlia* were reported to breed only in the wet season in the Alligator Rivers region of the Northern Territory, Australia, based on examination of museum specimens (James & Shine, 1985). James & Shine (1985) concluded that taxa such as *Carlia*, with origins in seasonally wet tropical areas, have maintained a historical association between breeding and the occurrence of seasonal rainfall. However, as in other tropical lizards that breed in association with the seasonal onset of rain, the factors that regulate the timing of breeding are not known in *Carlia*.

At the localities where *C. rostralis* were observed in the present study, a large community of reptiles exists at high densities. In this region, the onset and yearly occurrence of the wet season is relatively unpredictable. This is due to the stochastic occurrence of cyclonic rains; in more northern areas rain does occur in most years, but in these more southern areas dry summers occur at irregular intervals, approximately every three to six years. For lizards such as *C. rostralis* that live for one to five years (unpub. data, JMW), a dry summer can be a significant event in the life cycle. Furthermore, the onset of the wet season can vary up to four months, ranging from November to February, although normally commencing in late December or January.

In the Wet Tropics, the limited data available on reproductive patterns suggest that most species of lizards breed in the summer, with the onset of breeding commencing just prior to the start of the wet season (December & January; James & Shine, 1985). The conclusions from these observations have generally been that 'wet season' breeders reproduce in response to increased food availability (insect prey) that accompanics summer rains. These observations suggest that food availability may not play a critical role in the onset of reproduction, but that it may be important for the maintenance of reproduction later in the season.

I became interested in determining whether reproduction in *C. rostralis* in the Wet Tropics was regulated by seasonal rainfall. Of interest was the timing of reproduction in years when the wet season was delayed or did not occur (the latter is associated with the conditions of the Southern Pacific Oscillation, or El Niño). At the same time that the study of reproductive patterns in this species was conducted, the distribution and habitat preferences of *C. rostralis* were surveyed. Known localities obtained from records in the Queensland and Australian Museums (Ingram & Covacevich, 1989) between Townsville and Cairns, NEQ, were visited to establish and confirm the current distribution of this species.

METHODS

A study of *C. rostralis* was conducted in November-December, 1988; July, 1990-92, & January-February, 1991-93 at two field sites, Waterfall Ck, Waterview Shire, Ingham SF District, and at Waterview Ck, Jourama Falls NP, both approximately 60 km north of Townsville, NEQ. Both sites supported lowland vine thicket extending down the water course from rainforest at higher elevations. The vine thicket riparian zone extended approximately 100m to either side of the creek. Surrounding these areas was open sclerophyll forest. Several additional sites between Cairns and Townsville were visited to determine the extent of current distribution of *C. rostralis* in the southern portion of the Wet Tropics. These sites were mainly limited to locations in the vicinity of those published in Ingram & Covacevich (1989).

To assess sex and reproductive condition animals were hand captured using insect lures. On capture, individuals were measured snout to vent (±0.5 mm) and weighed (±0.2 gram). At the two field sites individuals were toe-clipped for long term population studies. Adult males were distinguished from adult females by the presence of a black gular region and bright orange lateral coloration. Minimum size (SVL) at sexual maturity was determined by the observation of the smallest size at which either sex was producing functional gametes. This was indicated by palpation of females in the field and dissection of museum specimens (JMW, unpublished observations). During the winter months, when immature and juvenile (< 35-40 mm SVL) individuals were present, coloration was not reliable as a means of determining sex, and individuals with a white throat less than 40 mm SVL were not sexed. Female reproductive condition was assessed by laparotomy or by palpation. Initially palpation followed by laparotomy was used to confirm the presence of previtellogenic follicles (no ovarian masses, < 3 mm in diameter), maturing follicles, (round, firm bodies > 3 mm in diameter), ovulated eggs (oval soft bodies > 5 mm in length), or shelled oviductal eggs (oval hard bodies > 6 mm in length). Subsequently females were palpated only, as this proved to be an accurate method of assessing reproductive condition. Since some females began developing a subsequent clutch, a portion of females had both maturing follicles and oviductal eggs. Most females in the study were recaptured numerous times before, during and after ovulation and after oviposition so that the timing and stage of the ovarian cycle was reconfirmed.

RESULTS

In the southern portion of its range, the current distribution of *C. rostralis* appears to resemble recent historical distribution as indicated by records in the Queensland and Australian Museums, and in Ingram & Covacevich (1989). At only a few sites were no *C. rostralis* found. At the majority, animals were either common or abundant. *C. rostralis* was locally abundant in vine thickets along creeks as well as in grassy riparian areas in open forest. This species was absent from dense rainforest such as that at higher elevations in the Seaview Ra. *C. rostralis* was restricted to the more mesic eastern localities in this southern area. No changes in habitat preference were noted between summer and winter seasons at the intensively studied localities. In the following list of *C. rostralis* sites surveyed, 1988–1993, the data are: (location surveyed; lat/long; habitat; date; status: A-abundant, C-common, U-uncommon, Ab-absent; AM/QM#, recorded locality).

1. Holloway Beach; 16 51/145 45; beach, residential; 7/90;Ab; AM R97693-4; Holloway Beach, via Casuarina St.
2. Davies Creek NP; 17 00/145 34; riparian open forest, rocks; 7/91; A; AM R53904; Davies Creek Rd., 16 miles SE Mareeba.
3. Palmerston NP; 17 36/145 45; rainforest; 12/88; Ab; --;--.
4. Millstream Falls NP; 17 39/145 27; grass in open forest, riparian; 12/88; C; AM R62272; Millstream Falls NP.
5. Murray Falls SF Park; 18 12/145 55; grass in open forest, riparian; 12/88; A; --;--.
6. Wallaman Falls NP; 18 38/145 33; grass in open forest, riparian; 12/88; U; AM R97690-2; 24.1 km ESE Wallaman Falls NP by road.
7. Jourama Falls NP; 18 52/146 07; grass in open forest, riparian vine thicket; 12/88-7/93; A; --; --.
8. Jourama Falls NP, upper drainage of east tributary of Waterview Ck; 18 52/146 07; rainforest; 7/91; Ab; --; --.
9. Waterfall Ck, Waterview Shire; 18 53/146 09; grass in open forest, riparian vine thicket; 12/88-7/93; A; --; --.
10. Waterfall Ck upper drainage, Waterview SF; 18 53/146 08; rainforest; 12/88; Ab; --;--.
11. Birthday Falls, Blackfriars SF; 18 59/146 09; rainforest; 12/88; Ab; --; --.
12. Hencamp Ck northern tributaries, Hinchinbrook SF; 19 01/146 21; rocky dry stream beds, open forest; 12/88; C; QM J27695; QM 32570-32575; Hencamp Creek, 5km N of 1 km E of Rollingstone.
13. Hencamp Ck, Hinchinbrook SF; 19 01/146 21; rocky dry stream bed, vine thicket; 7/93; A; QM J27695; QM 32570-32575; Hencamp Ck, 5km N of 1 km E of Rollingstone. ,
14. Little Crystal Ck, Mt Spec NP; 19 01/146 17; vine thicket, riparian; 12/88; U; AM R97675-6; 10 km W of Bruce Hwy via Paluma Rd.
15. McClellan's Lookout, Mt Spec NP; 19 01/146 12; grass in open forest; 12/88; U; --; --.
16. Cloudy Creek upper drainage , Mt. Spec NP; 19 01/146 12; rainforest; 12/88; Ab; --; --.
17. Pine Ck tributaries, Blackfriars and Kangaroo Hills Shires; 19 01/146 07; dry streams, open forest; 12/88; Ab; --;--.
18. Station Ck, Clemant SF; 19 07/146 26; rocks in dry stream bed, vine thicket; 7/93; A; --; --.

There is a high degree of sexual dimorphism in size in *C. rostralis*. Data from the first and second breeding seasons, in November & December, 1988, and January & February, 1991, are representative. Males were significantly longer and heavier than females and were heavier per unit of body length, except for the largest females (n, mean ± 1SE, of SVL and BW, of males: 21, 61.6 ± 3.5 mm, range, 53.0-69.0 mm; 5.4 ± 1.0 g, range, 4.0-7.0; of females: 21, 56.0 ± 2.8 mm, range, 50.0-60.0 mm; 4.4 ± 0.9 g, range, 3.0-7.0 g). At first breeding season, most of the adult females (12/14) were reproductively active during the study, with either preovulatory, postovulatory or, in one case, both types of follicles present in the reproductive tract. All females examined had two eggs. Two oviductal eggs, 8 x 4 mm, were found in two additional females that were kept as specimens. One of these individuals also had two yolking follicles, 1 mm in diameter, present in the ovary, indicating that females are capable of producing multiple clutches.

Based on direct observation (1988) or indirect inference from the presence of cohorts of hatchlings (1991 & 1992), ovarian recrudescence and egg-laying in this species began in November in all three years of the study. Reproductive activity was maintained through February in at least two years, regardless of the timing of the onset of the rainy season (Table 1). In 1988/89, females began developing mature follicles in early November and the first clutch of eggs was laid in mid-November; hatchlings first appeared in mid-December, suggesting that incubation time under the ambient conditions was 4-5 weeks. The onset of summer rains in 1988/89 occurred earlier than usual, in mid-December. In the second breeding season examined, 1990/91, breeding again commenced in November, as estimated by the presence of two cohorts of hatchlings in the population in mid-January. However, there was no onset of summer rains in this season, due to an occurrence of a severe drought as a result of a persistent Southern Pacific Oscillation. Finally, in the third year of the study, 1991/92, breeding commenced in November, estimated by the presence of three cohorts of hatchlings observed in late January, and continued through February. In mid-February, females ceased developing mature follicles and the reproductive season came to an end. In this year drought conditions persisted through early January, and heavy wet season rains did not occur until mid-February.

DISCUSSION

The current and future conservation status of *C. rostralis* in the southern portion of its range in the

Wet Tropics appears to be excellent. The habitat preferences and distributional requirements of the lizards in this area confirmed previous accounts (Ingram & Covacevich, 1989). *C. rostralis* is often observed basking on the rocky floor of the vine thicket. This heliothermy probably accounts for the species' absence in denser rainforest at higher elevations in the Seaview Ra. *C. rostralis* has a relatively diverse range of habitat preferences, being found also in grassy areas in open sclerophyll forest. However, the animals found in these localities usually are in close proximity to creeks and mesic riparian zones; in drier open forest on the western side of the range the species is absent.

Reproductive observations of *C. rostralis* at two localities (Waterfall & Waterview Cks) indicated that this species attains a large index of sexual dimorphism (1.1; ratio of mean SVL of males to females; Stamps, 1983). In addition, *C. rostralis* has a striking degree of sexual dichromatism that develops in the first year. These patterns of sexual dimorphism, although not uncommon amongst *Carlia* or other Australian scincids, are very different from that found in scincids that have been studied elsewhere, although few species have been studied (Stamps, 1983). This high degree of sexual dimorphism and dichromatism in *C. rostralis* appears to be related to breeding, as males do not usually develop the black gular region and bright orange, black and white markings on the lateral head, neck and thorax until breeding commences in the first year (Whittier & Scott, 1989; Whittier, 1991). These patterns of sexual dimorphism and dichromatism may be related to a highly competitive and ritualistic dominance hierarchy that is exhibited by male *C. rostralis* in both the laboratory and the field (Whittier & Martin, 1991).

Reproduction in *C. rostralis* is seasonal, with egg-laying beginning in November and December, and continuing to February. Egg production and hatchlings were not observed in July. In each year, nearly all adult females in the populations observed were reproductively active, having yolking follicles or oviductal eggs. Multiple clutches appeared to be produced by most females; in nearly every case of a recapture in the summer, developing follicles were detected in females that had previously been gravid. From these observations, I suggest that female *C. rostralis* produce three to four clutches of two eggs each during each breeding season (Whittier & Scott, 1989).

Although the breeding period in *C. rostralis* coincides with the usual time period of the wet season, breeding is not regulated by the onset of seasonal rain. Nor is breeding maintained by any factors such as purported increases in food availability associated with those rains. Although the factors that regulate timing of reproduction in this species are not known, two conclusions can be drawn from the study. First, that the timing of breeding is predictable and regulated in a precise manner, and second, that timing of breeding coincides with the most frequent occurrence of seasonal rain. I speculate that the timing of reproduction in this species is regulated either by seasonal changes in photoperiod or by an endogenous mechanism. These mechanisms would represent the best predictor of favourable conditions over the long term in this unpredictable environment.

Many factors, including physiology, phylogeny, zoogeographic history and life history traits may influence seasonal reproduction in squamate reptiles that inhabit subtropical and tropical environments (Shine, 1985; James & Shine, 1985; Auffenberg & Auffenberg, 1989; Vitt, 1990). From a physiological viewpoint, to understand the patterns of breeding in tropical lizard species and communities, an important consideration is the somatic condition of the female lizards (Bradshaw et al., 1991; Whittier, 1991a; 1993; Whittier & Tokarz, 1992). Patterns of abundance of food resources in the environment, assessed in the context of energy requirements for subsistence, growth, and reproduction of the species need to be considered. Because reptiles, particularly squamates, are limited by the energetic cost of female egg production, the mechanisms by which females assess somatic condition can be co-opted to regulate reproduction directly (Stearns, 1976; Tinkle & Hadley, 1985). Future studies should determine how

TABLE 1. Female egg-laying patterns of *C. rostralis*, NEQ, in relation to the onset of the wet season.

Time	Onset of Rain	Breeding Onset	Breeding Duration
Nov.1988-Dec. 1988	mid-Dec.	mid-Nov.	unknown
Jan. 1992-Feb. 1992	no season	mid-Nov.*	Feb.
Jan. 1993-Feb. 1993	Feb.	mid-Nov.**	Feb.

*Estimated from the presence of two cohorts of hatchlings present in early January.

**Estimated from the presence of three cohorts of hatchlings present in late January.

species such as *C. rostralis* precisely time and maintain reproduction in relatively unpredictable environmentslike the southern portion of the Wet Tropics.

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